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AN EEG PREDICTOR OF PERFORMANCE DECREMENT IN A VIGILANCE TASK

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Summary

An attempt was made to discover measures of EEG that could predict performance [illegible] long-term monitoring tasks in subjects who had not been previously sleep deprived. [illegible] took part in a study in which alpha numeric symbols were discriminated on 1100 trials [illegible] tinuous 3-hr "watches". Each subject completed the 3-hr watch on each of 3 consecutive [illegible] The reaction times for all trials on Day 2 and Day 3 were divided into the 10 percent [illegible] 10 percent slowest, and the errors of omission (EO) for each session. Brain activity at [illegible] vertex (C_z) was derived from the one-second period preceding each trial. Ensemble spectral analysis of the EEG was completed for each subject to yield intensity ([illegible]/Hz) at integral values of frequency from 1 to 12 Hz. It was found that the ratio of slow ([illegible] Hz) activity to intermediate 7-12 Hz) EEG activity at the vertex can differentiate EO trials from fast and slow responses and is reliable over at least 3 days. The technique could be used to monitor errors of omission in operational settings.

Introduction

There has been little success in finding EEG predictors of performance decrement in normally rested subjects. Williams et al., (1962) found that EEG frequency alone, measured in the 1-sec period just before a test signal, correlates about -.65 with reaction time in sleep deprived subjects, but their procedure could not predict reaction time during ordinary rested wakefulness. Boddy (1971) reported that there is no correlation between occipital alpha period and reaction time. He discussed his results with respect to a series of experiments done by Surwillo (1964) in which decision time was said to correlate significantly with brain wave period, cautioning the reader that alternative designs (Boddy's) did not corroborate Surwillo's hypothesis. However, the studies done by Surwillo sought a relationship across subjects--which, if valid, would mean that individuals with relatively slower EEG frequencies would require longer periods of time to make a decision.

Perhaps greater utility could be found in a relationship between EEG and reaction time, within subjects, such that the EEG could be used to predict performance decrement in vigilance situations before the decrement occurs. Such a predictor would be useful in continuous monitoring situations, such as radar or sonar or in other sustained operations, such as driving a truck or maintaining a watch.

Previous related work on sleep deprived subjects (Townsend and Johnson, 1979) led to a construction of a multiple regression equation in which the criterion variable was performance on a visual monitoring task and the predictors were spectral intensities (μ volts^2/ Hz). The source of the EEG was the scalp over the occipital region of the brain (0_1 referenced to linked mastoids). In post hoc scoring, the equation correctly identified 96% of the errors of omission and 85% of the "slow" reaction times. Practical applications of these data are limited because (1) the subjects were sleep deprived first, which may not be characteristic of most operational settings, and (2) the complex nature of the analysis system (step-wise multiple regression led to different beta weights in different subjects) does not lend itself to any ready application.

The present study addressed similar questions to see if (1) EEG predictors would work in situations where subjects had not been sleep deprived, but by virtue of the length of time and monotonous circumstances show significant decrements in performance, (2) the predictive power of EEG spectra is reliable over days, and (3) a simpler method of data reduction having greater practicality could be derived from the EEG spectra.

The present study is based on an old, but apparently unused rationale, and demonstrates that if the information known about EEG changes during lowered arousal is utilized, simple predictors of at least errors of omission can be derived from the spectrum of the EEG in subjects who have not been sleep deprived. The rationale for the present study is based on the original work by Brazier (1949), showing that frontal EEG during lowered vigilance consists of increased activity in the lower frequency bands together with decreased alpha activity. In the present work these two characteristics of the EEG were combined as a ratio to yield a single measure of EEG state during one-second epochs preceding a subject's response on a discrimination reaction time task.

The general hypothesis of the study was: Given the ratio of intensities in the 1 to 6 Hz range to 7-12 Hz EEG at the C_z lead, performance on a sustained monitoring task can be predicted in alert subjects. A more specific hypothesis, based on the given rationale, is that the ratio will be lowest preceding fast responses, intermediate preceding slow responses, and highest preceding errors of omission.

Method

Subjects. Ten male volunteers were obtained from the Naval Training Center and from the Naval Health Research Center. The mean age was 24 years.

Visual Monitoring. The performance of interest in this study was the ability to continue making decisions and rapid responses to visual symbols for 3-hr non-stop periods. A discrimination reaction task was constructed for this purpose. The intention was to simulate a situation in which a person monitoring a visual display might show fatigue and performance decrement without being aware of it. The task was repeated on three consecutive days. Alpha numeric symbols approximately 1 cm^2 appeared on a video screen 60 cm in front of the subject. The stimulus presentation rate was random with a mean of 10 sec and S.D. of 4 sec. Stimulus duration was 20 msec. The number of trials per 3-hr session was 1100. Subjects were instructed to sit as comfortably as possible in front of the display module and to move their bodies, especially their heads, as little as possible.

The task symbols were originated by computer graphic techniques and then recorded on video cassettes. The cassettes were then used as the stimulus source. The subjects were given a box with two response buttons. If the symbol on the screen was a "3" or an "A", then the subjects were to press the left button; if the symbol was any other alphanumeric character, then the right button was pressed. A "3" or an "A" occurred 10% of the time. Data analysis was based on all 1100 trials. The sequence of symbols was random. The cassettes were played in identical sequence for all 3-hr sessions for all subjects. All subjects completed the task on three separate days. Day 1 was treated as a practice session. Data analysis was completed only for Day 2 and Day 3.

EEG Recording. Biopotential electrodes were attached to the scalp at C_z and 0_1 and referenced to linked mastoids. A Beckman type R Dynograph with 9806 couplers was used to obtain the final EEG signal which was recorded on polygraph write-out and simultaneously post amplified for computer analysis.

Data Collection. A PDP 11/34 computer was connected on-line to the EEG output and to the subject's response buttons. The EEG was digitized at 256 points per second and stored on digital magnetic tape. The subject's response triggered a digital counter and printer. With each button press the reaction time in milliseconds was printed, along with real time to the nearest second. The time base was simultaneously recorded in binary coded decimel format on one channel of the tape recorder.

Data Reduction. At the completion of the data collection phase, the digitized tapes were rerun and a Fast Fourier Transform (FFT) was used to compute a spectrum of EEG from the C_z lead preceding slow, fast and EO trials. The fast trials were defined as the 10% fastest of the 1100 trials (i.e., the fastest 110 trials); the slow trials were defined as the 10% slowest of the 1100 trials, and the error-or-omission (EO) trials were those for which a reaction time greater than 2.5 sec occurred. The number of EOs per session varied from about 40 to over 100. The EEG spectrum with a frequency range of 1 to 20 Hz and resolution interval of 1 Hz was computed for all trials within each of the three categories defined above. The procedure was completed for all ten subjects on both days. The spectra are of the EEG activity occurring in the one-second epoch preceding each trial stimulus. Trials were edited for movement and sleep artifacts.

The pre-stimulus epoch was obtained as follows: The computer continuously monitored the digitized EEG tape from a given session. An 8-second time window was utilized in which 8 seconds of "current" EEG were stored. As new data came in, the old data were dropped. When a trial occurred that had been designated as Fast, Slow, or EO, the computer stopped the tape and selected the 256 data points that immediately preceded the event. This set of points constituted the one-second pre-stimulus EEG sample. The FFT was then applied to obtain the spectrum which was then printed in tabular form as intensity in microvolts ^{2}/Hz at each discrete frequency from 0 to 20 Hz. In addition, when all trials for a given condition (Fast, Slow, or EO) were in, the ensemble average spectrum was computed for that 3-hr session. This spectrum represents the mean intensity at each frequency for that condition. There were six such spectra for each subject on each day (2 leads x 3 conditions).

Results

The general characteristics of the vigilance task performance over the 3-hr period is summarized for the group in Figure 1. The group mean reaction time per 100-trial block is given as well as the mean number of errors of omission per 100-trial block. These curves show no major changes in reaction time and errors of omission during the 3-hr test period.

An example of the background EEG, in the form of the six ensemble average spectra for a typical subject is shown in Figure 2. It can be seen that the EEG at C_z has higher intensity in the low frequency range and corresponding lower intensity in the intermediate range during the EO condition. The ratio of the sum of intensities in the 1 to 6 Hz to 7-12 Hz band was obtained for each condition (fast trials, slow trials, EO) on each subject. The results for each individual are summarized in Table I. The data reduction and tests of significance were carried out on Day 2 and then in identical fashion on Day 3.

Looking at the group mean ratios for the 3 conditions, it can be seen that the ratios tend to be smallest during fast trials, intermediate during slow trials, and largest during the errors of omission. It is also clear that the biggest difference is between the error of omission response category and the other two (fast and slow). There is little difference between fast and slow trials.

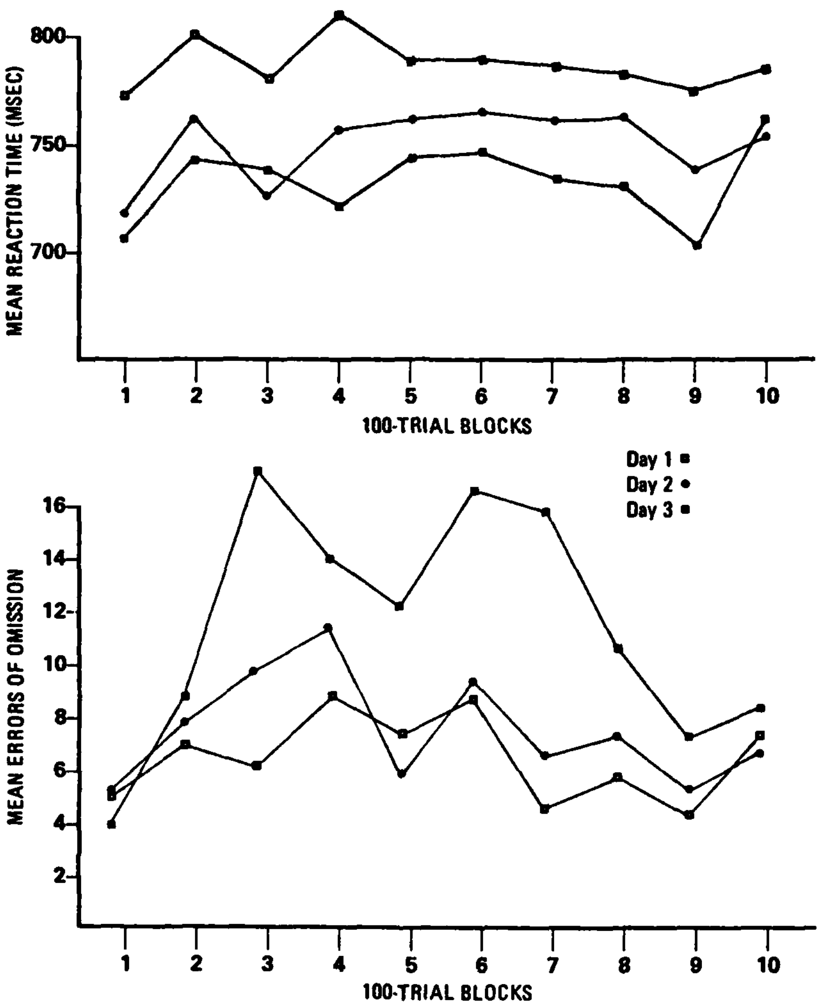

Figure 1. Mean reaction time and error of omission rate per 100-trial blocks during the 3-hour monitoring session.

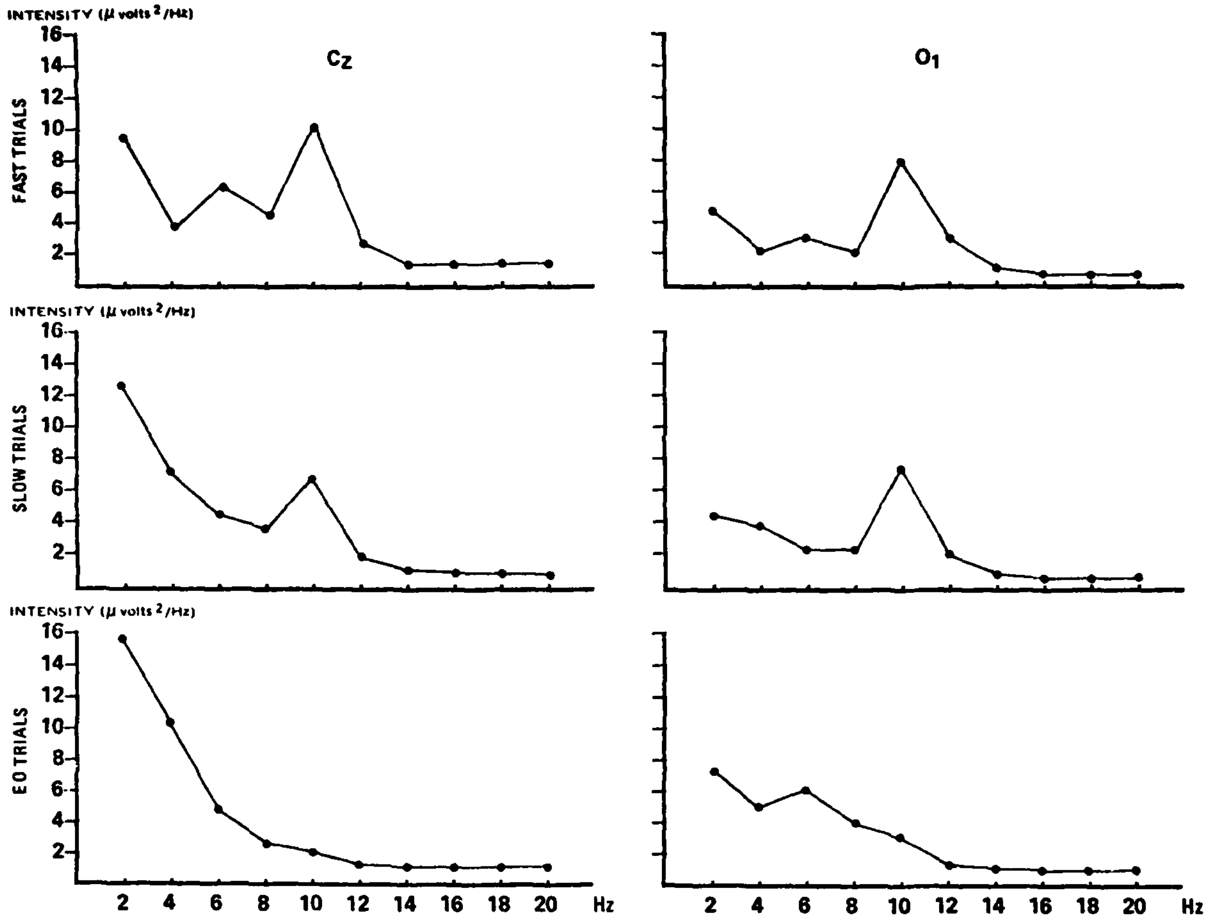

Figure 2. Ensemble average spectra for a typical subject. Each spectrum is based on the EEG activity (C_z or O_1) occurring in the one-sec epoch preceding stimulus onset.

TABLE I

The ratio of 1-6Hz to 7-12 Hz EEG spectral intensity at the vertex for each subject on Day 2 & Day 3

	Subject		FAST TRIALS (F)	SLOW TRIALS (S)	ERRORS OF OMISSION (EO)
	GO		1.41	1.13	1.35
	AN		4.52	5.79	9.64
	GA		2.59	2.58	2.04
	MA		2.95	3.66	4.52
Day 2	MU		1.27	2.23	5.28
	AL		1.02	0.98	3.12
	CO		1.28	1.22	3.17
	PA		6.41	6.57	11.11
	HA		0.81	0.76	1.98
	LU		1.31	1.39	1.96
		$\bar{X}$	2.36	2.63	4.42
		SE	.58	.65	1.07
	GO		1.21	1.35	2.16
	AN		5.20	5.02	3.35
	GA		2.38	3.05	3.82
	MA		2.58	2.84	4.71
Day 3	MU		1.62	1.64	5.02
	AL		1.13	1.29	1.18
	CO		1.04	1.11	1.62
	PA		5.39	5.54	2.59
	HA		0.90	0.98	1.38
	LU		1.76	1.70	2.05
		$\bar{X}$	2.32	2.46	2.79
		SE	.52	.52	.43

A post hoc evaluation of the distributions in Table I indicates several instances of extreme scores, thus precluding the use of a parametric test. The Kendall Nonparametric Coefficient of Concordance (W) was therefore chosen to test the hypothesis. The (W) statistic was computed for each day separately to test the hypothesis that the rank orderings across the 3 response categories was consistent across subjects. On Day 2, W was equal to .37 ($p<.05$) and on Day 3, W was .31 ($p<.05$), indicating that if the ratios are rank ordered within subjects, the ratios are significantly different between the 3 conditions on both days.

Discussion

The main hypothesis of this study was that the EEG ratio, as here defined, would be maximal preceding errors of omission, intermediate preceding slow responses and minimal preceding the fastest responses. It is clear from Table I that the main contribution to this effect is the relatively high EEG ratio associated with the errors of omission. The difference between the fast and slow responses appears to be too small to be of importance.

With respect to the three questions addressed in this study, it appears that first, EEG predictors of performance change during monitoring can work in situations where the subjects had not been previously sleep deprived. Second, the predictive power of the EEG ratio may not be practical by the third day because of the increased EO rate during the middle of the session. One might surmise that by the fourth day the EO rate would be even greater. Third, the EEG ratio is certainly simpler to implement than a step-wise multiple regression approach, but the question remains as to whether it can be used effectively on a trial-by-trial basis.

In the work reported by Townsend and Johnson (1979), the data seem to indicate that the EEG frequencies most closely related to RT were in the band from 8 to 20 Hz. They reported a negative correlation between RT and the intensity in this band (i.e., higher intensity in this band was associated with short reaction times). In the present study it is the increased activity in the slow band and/or the decreased activity in the intermediate band that seems to maximally separate the EO trials from fast or slow trials.

The present study also indicates that the EEG at the vertex may be sufficient to detect changes in the slow and intermediate frequency range that are associated with errors of omission. Brazier's (1949) work, taken together with the spectra shown in Figure 1 in this study, suggests that the changes are in the frontal regions more than occipital.

On Day 3 there were some unusual reversals in the general trend that had been found on Day 2. It is most apparent in subjects AN and PA, and consists of unusually low EEG ratios preceding the errors of omission. Referring back to Figure 1, it can be seen that the EO rate is high during the middle part of the 3-hr task. This suggests that at least some subjects are probably experiencing lapses in consciousness with corresponding increases in EO rate. Just why the EEG ratio may be relatively low preceding EO responses in some individuals can only be speculated on at present. One possibility is that these subjects were actively combating drowiness and fatigue with increased muscle tension, which contributes more to the spectral intensity in the 7-12 Hz band than the 1-6 Hz band. The EEG ratio under these circumstances would be relatively low. It is therefore apparent that if such a system were to be used as part of a vigilance monitor, careful attention would need to be given to the interaction between EEG and muscle activity.

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Ten subjects took part in a monitoring task in which alpha numeric symbols were discriminated on 1100 trials during continuous 3-hr "watches". Each subject completed a 3-hr watch on 3 consecutive days. The reaction times for all trials on day 2 and day 3 were divided into the 10 percent fastest, 10 percent slowest, and the errors of omission (EO) for each session. Brain activity at the vertex (C_z) was derived from the one-second period preceding each trial. Ensemble spectral analysis was completed for each subject to yield intensity

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20. Abstract (continued)

(μ volts^2/Hz) at integral values of frequency from 1 to 20 Hz. It was found that the ratio of slow (1-6 Hz) activity to intermediate (7-12 Hz) EEG activity at the vertex can differentiate EO from fast and slow trials thus supporting the contention that brain activity recorded at the scalp can be used to monitor vigilance level in rested subjects. The technique could be used to monitor vigilance states in operational settings.